

1 I CLAIM:

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3 1. Endothermic catalytic reaction apparatus
4 comprising:

5 a) a U-shaped flow through tubular reaction
6 chamber disposed upright within a combustion chamber,
7 and a catalyst contained within said reaction chamber
8 for the conversion of hydrocarbon to industrial gases
9 by reaction with steam; said reaction chamber having an
10 upper portion, and there being a convection chamber
11 extending about said upper portion to enhance the
12 transfer of heat from combustion products in the
13 reaction chamber, and

14 b) a radiant burner generally vertically
15 disposed within the combustion chamber and having a gas
16 permeable zone that promotes the flameless combustion
17 of fuel and oxidant supplied to said burner in order to
18 heat a metal fiber surface of the burner to
19 incandescence for radiating heat to the reaction
20 chamber; said radiant burner configured so that the
21 angle of radiation is predominantly incident upon the
22 surface of the tubular reaction chamber.

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1 2. The combination of claim 1 wherein said
2 tubular reaction chamber comprises a tube having outer
3 diameter or diameters ranging from about $\frac{1}{4}$ inch to
4 about 4 inches along the tube length.

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7 3. The combination of claim 1 wherein said
8 tubular reaction chamber is sized for creation of mass
9 velocities ranging from 400 lb/ft²/h to 1500 lb/ft²/h.

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12 4. The combination of claim 1 wherein said
13 catalyst in the tubular reaction chamber has average
14 catalyst particle diameters ranging from 1/8 to 1 inch
15 for producing gas pressure drops ranging from 1 psi to
16 8 psi during flow through the reaction chamber.

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19 5. The combination of claim 1 wherein said
20 tubular reaction chamber has a gas exit end temperature
21 ranging from 1150°F to 1400°F when heated by said
22 radiant burner, in operation.

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1 6. The combination of claim 1 wherein said
2 tubular reaction chamber has legs and an arc-shaped
3 bend connecting said legs, and said legs and bend have
4 maximum tube wall temperatures ranging from 1300°F to
5 1600°F when heated by said radiant burner, in
6 operation.

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9 7. The combination of claim 1 wherein said
10 tubular reaction has average heat fluxes ranging from
11 3,000 btu/ft²/h to 10,000 btu/ft²/h, when heated by
12 said radiant burner in operation.

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15 8. The combination of claim 1 wherein said
16 tubular reaction chamber is sized to have capacity to
17 generate hydrogen plus carbon monoxide product in
18 volumetric quantities ranging from 50 SCFH to between
19 500 and 1500 SCFH.

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22 9. The combination of claim 1 wherein said
23 radiant burner comprises a supported porous ceramic
24 material having extended life at operating temperatures
25 up to 2100°F.

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1 10. The combination of claim 1 wherein said
2 radiant burner comprises a supported metal fiber
3 material consisting essentially of an alloy containing
4 principally iron, chromium, and aluminum and smaller
5 quantities of yttrium, silicon, and manganese, said
6 alloy having extended life at operating temperatures up
7 to 2000°F.

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10 11. The combination of claim 1 wherein said
11 radiant burner is configured to direct radiation at an
12 included angle of radiation between 45-180 degrees.

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15 12. The combination of claim 1 wherein said
16 radiant burner has a hemispherical shape.

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19 13. The combination of claim 1 wherein said
20 radiant burner has surface temperatures ranging from
21 1500°F to 1900°F, in operation.

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1 14. The combination of claim 1 wherein said
2 radiant burner has an operating combustion intensity
3 typically ranging from 150,000 btu/ft²/h to
4 350,000 btu/ft²/h, wherein the combustion intensity is
5 defined as the higher heating value of the fuel
6 combusted divided by the permeable radiant burner
7 surface area.

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10 15. The combination of claim 1 wherein said
11 radiant burner has an operating excess air ratio
12 typically ranging from 30% to 100%, wherein the excess
13 air ratio is defined as percent combustion air in
14 excess of the stoichiometric amount required for
15 complete combustion of the burner fuel.

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1 16. Endothermic catalytic reaction
2 apparatus, comprising
3 a) a combustion chamber,
4 b) a tubular reaction chamber having two
5 generally tubular legs extending in generally parallel,
6 spaced apart relation within the combustion chamber,
7 c) catalyst within said reaction chamber
8 for reacting with a hydrocarbon and steam received
9 within the reactor chamber, to produce hydrogen and
10 carbon dioxide,
11 d) a generally tubular radiant burner
12 within the combustion chamber and extending in
13 generally parallel relation to at least one of said
14 legs, said burner spaced from said legs,
15 e) said two legs having axes, and said
16 tubular burner having an axis which is spaced in offset
17 relation to a plane defined by said leg axes.

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20 17. The combination of claim 16 wherein said
21 burner axis is approximately equidistant from said leg
22 axes.

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1 18. The combination of claim 16 wherein said
2 burner has heat radiating surfaces configured to
3 radiate heat predominately in directions toward said
4 legs.

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7 19. The combination of claim 16 wherein said
8 legs are in series communication.

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11 20. The combination of claim 16 wherein the
12 burner has a gas permeable metal fiber zone γ_1 , and
13 non-gas permeable zone γ_2 , where γ_1 faces said legs
14 and γ_2 faces away from said legs, γ_1 subtending an
15 angle that is less than 180°.

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1 21. Endothermic catalytic reaction apparatus
2 comprising:

3 a) a helical tubular flow through reaction
4 chamber disposed within a combustion chamber, and
5 catalyst contained within said reaction chamber for the
6 conversion of hydrocarbon to industrial gases by
7 reaction with steam; said helical tubular reaction
8 chamber having an upper portion, and there being a
9 convection chamber extending about said upper portion
10 to enhance the transfer of heat from combustion
11 products in the reaction chamber and an exit section to
12 convey reaction products to the exit means, and

13 b) a radiant burner vertically disposed
14 within said combustion chamber and having a gas
15 permeable zone that promotes the flameless combustion
16 of fuel and oxidant supplied to said burner in order to
17 heat the metal fiber surface of the burner to
18 incandescence for radiating heat energy to the reaction
19 chamber; said radiant burner configured to radiate
20 uniformly in radial directions.

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23 22. The combination of claim 21 wherein said
24 tubular reaction chamber comprises a tube having outer
25 diameters ranging from about $\frac{1}{8}$ inch to about 4 inches,
26 along the tube length.

1 23. The combination of claim 21 wherein said
2 tubular reaction chamber defines a coil having an outer
3 coil diameter ranging from 6 to 36 inches.

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6 24. The combination of claim 21 wherein said
7 helical tubular reaction chamber is for creation of
8 mass velocities ranging from
9 400 lb/ft²/h to 1500 lb/ft²/h.

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12 25. The combination of claim 21 wherein said
13 catalyst in the helical tubular reaction chamber has
14 average catalyst particle diameters ranging from ¼ to 1
15 inch for producing gas pressure drops ranging from 1
16 psi to 8 psi during flow through the reaction chamber.

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19 26. The combination of claim 21 wherein said
20 helical tubular reaction chamber has gas exit end
21 temperature ranging from 1150°F to 1400°F, when heated
22 by said radiant burner, in operation.

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1 27. The combination of claim 21 wherein said
2 helical tubular reaction chamber has maximum tube wall
3 temperatures ranging from 1300°F to 1600°F, when heated
4 by said radiant burner, in operation.

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7 28. The combination of claim 21 wherein said
8 helical tubular reaction chamber has average heat
9 fluxes ranging from 3,000 btu/ft²/h to
10 10,000 btu/ft²/h, when heated by said radiant burner in
11 operation.

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14 29. The combination of claim 21 wherein said
15 helical tubular reaction chamber is sized to have
16 capacity to generate hydrogen plus carbon monoxide
17 product in volumetric quantities ranging from 50 SCFH
18 to between 100 and 1500 SCFH.

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21 30. The combination of claim 21 wherein said
22 radiant burner comprises a supported porous ceramic
23 material having extended life at operating temperatures
24 up to 2100°F.

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1 31. The combination of claim 21 wherein said
2 radiant burner comprises a supported metal fiber
3 material consisting essentially of an alloy containing
4 principally iron, chromium, and aluminum and smaller
5 quantities of yttrium, silicon, and manganese, said
6 alloy having extended life at operating temperatures up
7 to 2000°F.

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10 32. The combination of claim 21 wherein said
11 radiant burner is configured to radiate heat energy in
12 a substantially uniform radial pattern.

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15 33. The combination of claim 21 wherein said
16 radiant burner has surface temperatures ranging between
17 1500°F and 1900°F, in operation.

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20 34. The combination of claim 21 wherein said
21 radiant burner has an operating combustion intensity
22 typically ranging from 150,000 btu/ft²/h to
23 350,000 btu/ft²/hr, wherein the combustion intensity is
24 defined as the higher heating value of the fuel
25 combusted divided by the permeable radiant burner
26 surface area.

1 35. The combination of claim 21 wherein said
2 radiant burner has an operating excess air ratio
3 typically ranging from 30% to 100%, wherein the excess
4 air ratio is defined as percent combustion air in
5 excess of the stoichiometric amount required for
6 complete combustion of the burner fuel.

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9 36. The combination of claim 22 wherein the
10 coil has free area in the range 50% to 75%, wherein the
11 free area is defined as the ratio of the free area
12 between successive coil turns and the cylinder that
13 bisects the helical coil circle.

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16 37. The combination of claim 21 wherein the
17 convection chamber has an inlet within the combustion
18 chamber, and an outlet outside the combustion chamber.

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21 38. The combination of claim 1 including a
22 fuel cell in operating communication with said reaction
23 chamber, to receive hydrogen therefrom.

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1 39. The combination of claim 21 including a
2 fuel cell in operating communication with said reaction
3 chamber, to receive hydrogen therefrom.

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6 40. The method of converting a hydrocarbon
7 to industrial gases, that includes:

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9 a) providing a U-shaped flow through
10 tubular reaction chamber disposed upright within a
11 combustion chamber, and a catalyst contained within
12 said reaction chamber for the conversion of said
13 hydrocarbon to said industrial gases by reaction with
14 steam; said reaction chamber having an upper portion,
15 and there being a convection chamber extending about
16 said upper portion to enhance the transfer of heat from
17 combustion products in the reaction chamber,

18 b) providing a radiant burner generally
19 vertically disposed within the combustion chamber and
20 having a gas permeable zone that promotes the flameless
21 combustion of fuel and oxidant supplied to said burner
22 in order to heat a fiber surface of the burner to
23 incandescence for radiating heat to the reaction
24 chamber; said radiant burner configured so that the
25 angle of radiation is predominantly incident upon the
surface of the tubular reaction chamber,

1 c) supplying said hydrocarbon and steam to
2 the reaction chamber heated by said radiant burner,
3 d) and removing said industrial gases
4 including hydrogen from the reaction chamber.

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7 41. The method of claim 40 including
8 providing a gas conditioning system and fuel cell, and
9 supplying said hydrogen to said fuel cell.

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12 42. The method of claim 40 wherein said
13 fiber surface of the burner consists of at least one of
14 the following:

15 a) ceramic

16 b) metal.

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1 43. Endothermic catalytic reaction apparatus
2 that includes a combustion chamber, comprising:
3 a) a straight tubular outer conduit
4 concentrically disposed around an inner conduit to form
5 a reaction chamber containing catalyst in the annular
6 space between the outer conduit wall and the inner
7 conduit wall, for conversion of hydrocarbon to
8 industrial gases by reaction with steam, and an inner
9 conduit defined space for the return flow of reactant
10 gases to an exit means; said tubular reaction chamber
11 having one end that extends into the combustion chamber
12 and an opposite end that extends outside of the
13 combustion chamber, and there being inlet means that is
14 in communication with the annular space and an exit
15 means that is in communication with the inner conduit
16 defined space,
17 b) and a radiant burner vertically disposed
18 within said combustion chamber and having a gas
19 permeable zone that promotes the flameless combustion
20 of fuel and oxidant supplied to said burner in order to
21 heat the metal fiber surface of the burner to
22 incandescence for radiating heat energy to the reaction
23 chamber.
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1 44. The combination of claim 43 wherein a
2 multiplicity of said tubular reaction chambers are
3 provided and are concentrically disposed around a
4 centrally located and vertically disposed cylindrical
5 radiant burner having a 360 degree radiant arc.
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8 45. The combination of claim 43 wherein
9 there is a convection chamber extending about a portion
10 of the tubular reaction chamber in the proximity of the
11 end containing the reactant gas inlet and outlet means
12 to enhance heat transfer from combustion products; said
13 convection chamber having an inlet means that is in
14 communication with the combustion chamber and an exit
15 means for combustion products that is outside the
16 combustion chamber.
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19 46. The combination of claim 43 wherein the
20 reactant gases flowing inside the inner conduit
21 transfer heat to the reaction chamber.
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24 47. The combination of claim 43 wherein said
25 radiant burner is comprised of a supported metal fiber
26 material.

